RESEARCH ARTICLE

Experimental Study on Suitability of Geopolymer Concrete Paver on Medium Traffic Condition Highway

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ABSTRACT: The Geopolymer concrete is under research since more than a decade now. With the improvement in understanding the behavior of geopolymer concrete through many researches certainly makes the geopolymer concrete as a replacement for the conventional concrete particularly in precast industry. The present research paper is aiming to use the geopolymer concrete using manufactured fine aggregate paver at two different curing conditions 7 days ambient curing and 24 hours oven curing at 60 ^{0}C. An attempt has been made to use the geopolymer concrete in the medium traffic condition. The minimum grade of concrete to be used in medium traffic condition as per IS15658-2006 is M40. To meet the suitability, trial mixes are prepared for M40 geopolymer grade concrete under varying curing conditions to check the dry density, water absorption, compressive strength, flexural strength and abrasion resistance properties. The experimental study justifies that the variation in the compressive strength by oven curing is 20% higher than the ambient curing with limited variation in flexural strength. It can be concluded that, irrespective of curing condition the designed mix suits the desired specification.

KEYWORDS: Geopolymer, concrete, water absorption, compressive strength

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1. INTRODUCTION

Geopolymer concrete is an alternative construction material which is produced by the chemical action of inorganic molecules. Otherwise geopolymer is an inorganic alumino- hydroxide polymer synthesized from a naturally available or any byproduct predominant in silica (SiO_2) and alumina (Al_2O_3) materials. Geopolymers are formed by alkali-activating a variety of materials (rich in silica and alumina) including fly ash, blast furnace slag, thermally activated clays etc. to produce a cement-like material. The term Geopolymer is introduced to represent the mineral polymers which results from geochemistry. The process involves a chemical reaction under highly alkaline conditions on Si-Al minerals, yielding polymeric Si-O-Al-O bonds in amorphous form [1]. It has emerged as better construction material for future due to its mechanical and durability properties. There are many scopes where geopolymer concrete is best suited than the conventional concrete, and one particular scope is precast industry. In the present research, the suitability of geopolymer concrete as interlocking zigzag concrete pavers is being tested.

A paver can be defined as a paving stone, tile, brick or brick-like piece of concrete commonly used in exterior flooring. In a factory, concrete pavers are made by pouring a mixture of concrete and some type of coloring agent into a mold of some shape and allowed to set. Pavers are applied on a standard concrete foundation, spreading sand on top, and then laying the pavers in the desired pattern. Concrete Pavers have wide applications in the construction roads, driveways, patios, walkways and other Outdoor platforms. Aaron et al [6] and Mali and Renjan[7] worked on combined sustainability, curing free with waste management to produce M40 geopolymer concrete pavers showing that they have excellent compressive strength within short period of 3 day suitable for practical application. Banupriya et al[8] studied mainly on use of quarry dust on replaced with river sand for making geopolymer bricks and paver blocks with different percentage variations in flyash and ggbs. Karunarathne et al [9] worked on geopolymer concrete blocks for different strength classes, namely 30MPa, 40MPa, 50MPa in oven and ambient cured condition. Kumutha et al investigated on development of geopolymer paver blocks of I shaped for their compressive, split tensile, flexural and abrasive strength as per Indian Standards 15658:2006 [10]. Kewal et al [11] worked on replacement of fine aggregate in the range of 0%, 20%, 40%, 60%, 80% and 100% in geopolymer paver block by used foundry sand for determining optimum replacement of fine aggregate to be found to be 60%. Abhay et al [12] compared geopolymer paver block using natural aggregate and recycled aggregate as fine aggregate and slag as coarse aggregate by experiments. The geopolymer paver block with recycled aggregates showed all the test results within limit as per IS15658 to be used in residential driveways, light vehicles/public pedestrian and light vehicle paths. The present study aimed at achieving a zig-zag geopolymer concrete paver of M40 grade which is suitable for Medium traffic condition highway. The test results conducted are as per IS15658-2006.

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2. MATERIALS USED & THEIR PROPERTIES

2.1 Ground Granulated Blast Furnace Slag

(GGBS): GGBS available from local market is used for the present study as a binding material. GGBS is rich in oxides of aluminium and silicon.

2.2 Alkaline Solution:

A combination of sodium hydroxide and sodium silicate is taken as alkaline solution or binding solution. The sodium hydroxide solids available in commercial grade in the form of flakes are used with 99% purity, obtained from local suppliers. The sodium hydroxide (NaOH) solution 10M is prepared by dissolving the pellets in water. Sodium silicate (Na_2SiO_3) solution obtained from local suppliers was used. The chemical composition of the sodium silicate solution was Na_2O=13.7%, SiO_2=29.4%, and water 55.9% by mass. These two solutions were mixed in 1:1 proportion by weight, 24 hours prior to the concrete casting [2].

2.3 Aggregates:

Fine Aggregate

M-sand or crushed aggregate is used as fine aggregate. The gradation of the sand was determined by sieve analysis as per IS 383 (1970) and confirmed to Zone II.

Coarse aggregate

Locally available Crushed granite stones having the maximum size of 10 - 12mm are used in this research work.

2.4 Water

Water that is clean and free from injurious amounts of oils, acids, alkalis, salt, sugar, organic materials or other substances that may be deleterious to concrete is used. Extra water is added to improve the workability.

2.5 Admixture

Various superplasticizers can be used to substantially improve the workability of fresh concrete. Therefore, admixture based on the polycarboxylate ethers is used to improve the workability of concrete in the present research.

3. EXPERIMENTAL METHODOLOGY

The pavers selected for the present study are assumed to be used in Medium traffic category like city streets, small and medium market roads, low volume roads, utility cuts on arterial roads, etc. Medium traffic condition is defined as a daily traffic of 150-450 commercial vehicles greater than 30kN laden weight, or an equivalent of 0.5 to 2.0 Million Standard Axles for a design life of 20 years [3]. The grade of concrete for this category is minimum M40. Therefore in the present study experiments are conducted on M40 grade concrete.

3.1 Specimens

The paver block chosen for the present investigation is ZIG-ZAG- shaped paver block having a dimension of 248 X 124 X 80mm. The aspect ratio of the block is the ratio between the Length (L) to the Thickness (T) of the concrete paver block (L/T). The IS 15658: 2006 specifies that the minimum and maximum block thickness shall be 50mm and 120mm respectively and the maximum aspect ratio of the block is 4. For the block considered in the present study, the aspect ratio is found to be 3.1 which is within the limit of 4. Samples are prepared in order to determine various properties such as density, compressive strength, flexural strength, water absorption and abrasion resistance.

3.2. Geopolymer concrete mix design for paver blocks:

As there are no standard codes established for the mix design of geopolymer concrete in any part of the world, so for the mix design process is carried on basis of some of some thumb rules assuming density of concrete as 2400kg/m^3. The mix design process adopted is as per Lloyd and Rangan [4] by assuming the density of concrete as 2400 kg/m^3 out of which the quantity of aggregates was fixed as 77%. The fine aggregates are taken as 30% of the total aggregates. Then by assuming alkaline liquid to binder ratio as 0.4 and sodium silicate to sodium hydroxide ratio as 2.5, the proportions of various ingredients were arrived at. Here the binder consists of GGBS. The detail of mix proportions adopted after many trials is shown in Table 2.

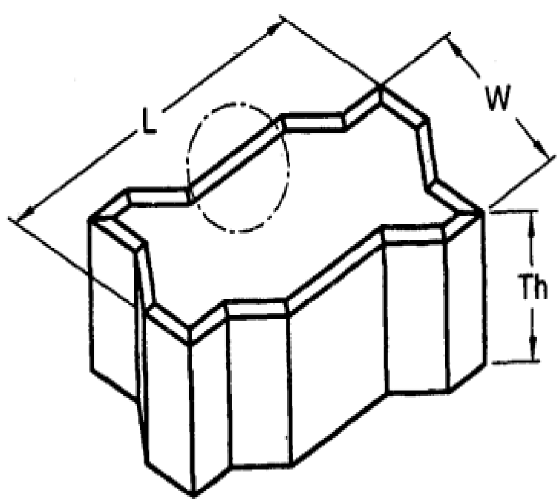

Figure 1 Length (L), Width (W) and Thickness (Th) of Paver blocks

3.3 Mixing of Geopolymer Concrete

According to Nuruddin et al. [5] mixing process can be divided into two stages, dry mix and wet mix. Initially coarse aggregate, fine aggregate and GGBS will be mixed together in rotating pan mixer for 3 to 5 minutes. The alkaline solution is prepared by mixing sodium hydroxide solution with sodium silicate solution one day before making the geopolymer concrete to get the desired alkaline solution. The liquid part of the mixture, i.e., the alkaline solution, extra water and the super plasticizer, should be premixed thoroughly and then added to the dry mixture. The wet mixing can be done for 1.5 to 3 minutes. Fresh geopolymer concrete is then hand mixed to ensure the mixture homogeneity. The alumino-silicate gel is highly viscous and mixing agitation can easily encapsulate air into the matrix. Mechanical vibration of the formed molds serves to reduce this potential and greatly improves the overall strength of the hardened geopolymer concrete. A freshly cast geopolymer concrete paver is shown in Fig.2. The curing regime adopted in present study is ambient curing for 7 days open to atmosphere in the laboratory and oven curing at 60 ^{0}C for 24 hours.

Table 1: Physical properties of aggregates

S. No.	Property	Fine aggregate	Coarse aggregate
1.	Specific gravity	2.51	2.83
2.	Fineness modulus	2.87	7.55

Table 2. Mix Proportion adopted for M40 grade geopolymer concrete.

Sl no.	Materials	Mass, kg/m^3
1	GGBS	430
2	Fine sand	560
3	Coarse aggregates	1294
4	NaOH solution	45
5	Na_2SiO_3 solution	113
6	Water	90
7	Extra Water	5% of binder
8	Superplasticiser	1.5% of binder

Figure 2. Geopolymer concrete cast in paver moulds

Figure 3. Geopolymer concrete pavers after demoulding.

4. RESULTS AND DISCUSSIONS

The physical tests like dry density, water absorption, compressive strength, flexural strength and abrasion resistance are carried in the present work to study the mechanical properties of geopolymer concrete paver in different curing regimes. All the tests are carried as per IS 15658-2006. The results are discussed below.

4.1 Dry Density

The densities of pavers after 7 days in dry state are recorded to check for achieving the minimum required density assumed during the mix proportioning. The results for dry densities are shown in Table 3. The average dry density for oven cured specimen is 2559.8kg/m^3 and that of ambient cured specimen is 2483.7kg/m^3. Both densities are greater than conventional concrete density. The key for strong paver block is the density; high dense paver blocks can resist abrasion better and have better resistance to freezing and thawing. Geopolymer paver blocks are found to have higher density than OPC paver blocks.

4.2 Water Absorption

The desired specification for 24 hour water absorption as per IS-15658: 2006, should be less than 7% for individual blocks. The water absorption for various samples is shown in Table 4. Geopolymer paver blocks cured at ambient cured specimen is 0.95% against that of oven cured specimen which has water absorption of 1.45% (as in Fig. 5). Thus all pavers met the IS specification irrespective of the curing condition. It is observed that oven cured specimens have higher water absorption than the ambient cured specimen. While curing under oven, there is a chance of escape of water from the top surfaces than from inner leading to the formation of micro-surface cracks. So, presence of micro-cracks may have increased the water absorption. Table.4 depicts the individual water absorption values for both oven and ambient curing regime.

Table 3. Dry densities for geopolymer pavers at oven and ambient curing regime

Sl.No	Dry Density (Oven Curing) kg/m^3	Dry Density (Ambient Curing) kg/m^3
1	2561	2490
2	2552	2510
3	2560	2500
4	2501	2473
5	2612	2479
6	2573	2450

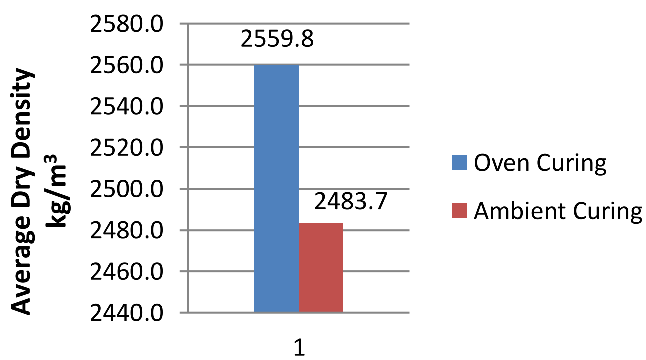

Figure 4. Average Dry densities of geopolymer concrete pavers

Table 4. Water Absorption (%) for geopolymer pavers at oven and ambient curing regime

Sl.No	Water Absorption (Oven Curing) %	Water Absorption (Ambient Curing) %
1	1.52	0.693
2	1.32	0.874
3	1.45	0.869
4	1.8	1.312
5	0.9	0.71
6	1.7	1.26

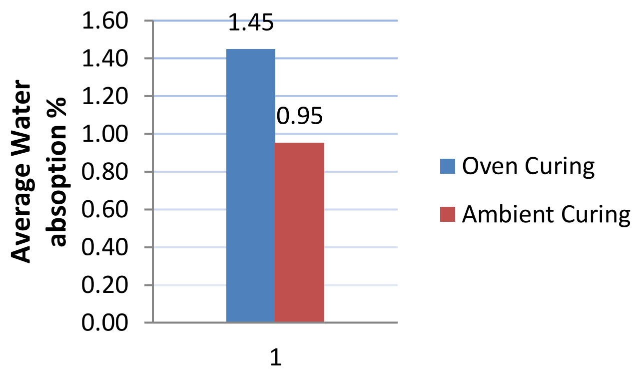

Figure 5. Average water absorption of geopolymer concrete pavers

Table 5. Compressive Strength for geopolymer pavers at oven and ambient curing regime

Sl.No	Compressive Strength (Oven Cured) N/mm^2	Compressive Strength (Ambient Cured) N/mm^2
1	61.52	49.75
2	62.55	45.65
3	59.5	51.50
4	68.7	47.24
5	63.2	52.68
6	63.7	53.40

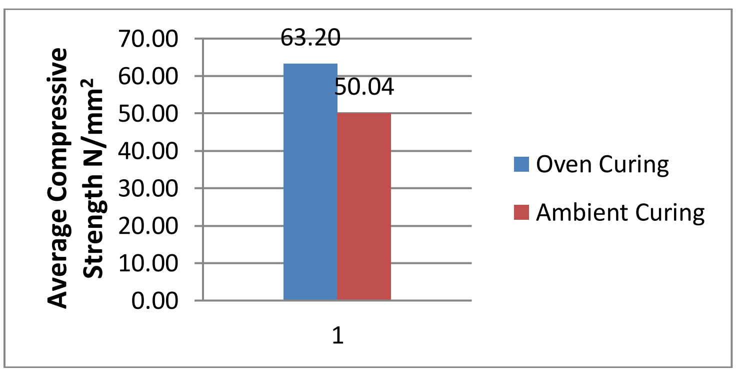

Figure 6. Average compressive strength of geopolymer concrete pavers

Table 6. Flexural Strength for geopolymer pavers at oven and ambient curing regime

Sl.No	Flexural Strength (Oven Cured) N/mm^2	Flexural Strength (Ambient Cured) N/mm^2
1	1.65	1.92
2	1.75	2.20
3	1.92	2.15
4	1.95	1.87
5	1.79	2.40
6	1.95	2.23

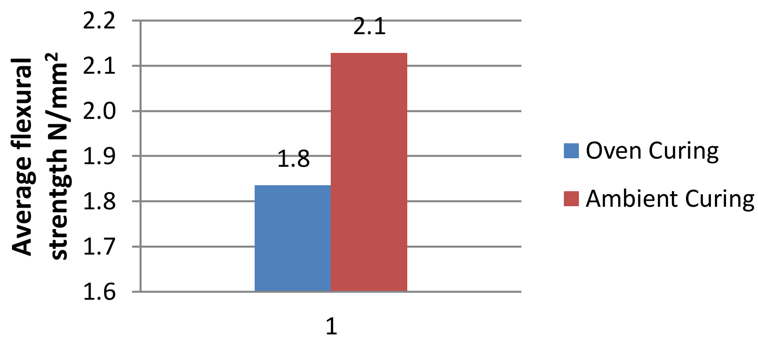

Figure 7. Average compressive strength of geopolymer concrete pavers

Table 7. Abrasion resistance for geopolymer pavers at oven and ambient curing regime

Sl.No	Abrasion Resistance (Oven Cured) mm^3	Abrasion Resistance (Ambient Cured) mm^3
1	901.23	840.00
2	912.25	845.12
3	924.72	842.15
4	890.43	860.23
5	945.23	870.63
6	925.52	843.36

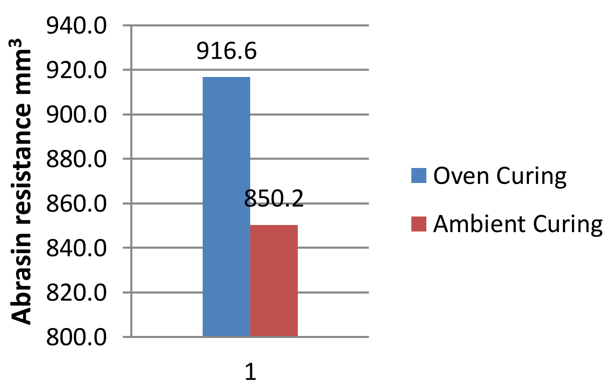

Figure 8. Average abrasion resistance of geopolymer concrete pavers

4.3 Compressive Strength

The oven cured specimen had a better strength of 63.20 N/mm^2 against that of ambient cured specimen of strength $50.04N/mm^2$ (see Fig. 6). It is evident that geopolymerisation process requires a higher temperature for better strength results as the dissolution of silica and alumina in alkaline solution is better at higher temperature. But for the present study is to aim at producing the M40 grade concrete at ambient curing condition, which is being achieved. So, producing geopolymer concrete paver at ambient condition becomes economical and eco-friendly as it does not require higher temperature. Table 5 shows the individual paver results for compressive strength at 7 days for both oven and ambient curing regime.

4.4 Flexural Strength

There is no much substantial improvement in the flexural strength of geopolymer pavers cured in both oven and ambient conditions. Table 6 depicts the flexural strength behavior of paver in both conditions. Fig. 7 represents the average flexural strength of geopolymer pavers.

4.5 Abrasion Resistance

Geopolymer paver blocks are found to have superior abrasion resistance than OPC pavers. As per IS 15658:2006 abrasion value should be reported to nearest to whole number of $1000mm^3$ per $5000mm^2$ and the average value obtained for oven cured specimen is

916.6 mm^3 and for ambient cured specimen is 850.2 mm^3 which are less than 1000mm^3. Thus the pavers can be used for medium traffic region. Table 7 depicts the abrasion resistance of individual pavers cured in both oven and ambient condition. The average abrasion resistance is depicted in the Fig. 8.

5. CONCLUSIONS

Based on the results of research work following conclusions are drawn.

- Geopolymer concrete is an excellent alternative to Portland cement concrete. Based on the present research work geopolymer concrete can be effectively used for manufacture of precast concrete paver block.
- Geopolymer pavers achieved very early high compressive strength that is 63.20N/mm^2 in oven cured condition and 50.04 N/mm^2 in ambient cured condition at 7 days. Therefore, geopolymer pavers can be suitably used in the construction for medium traffic condition.
- No need of water curing for geopolymer paver, this can save a lot of curing time and space at manufacturing unit. Moreover the precious water used for curing in conventional concrete can saved. This makes the use of these pavers a sustainable practice.
- No substantial improvement in the flexural strength for both oven cured and ambient cured specimen. But, the flexural strength is comparable to that of same grade of conventional concrete.
- Geopolymer paver blocks had average water absorption of 1.45% for oven cured specimen and 0.95% for ambient cured specimen which is better than water absorption on normal concrete blocks.
- The average dry density of Geopolymer pavers is comparable with conventional concrete. Thus the key for strong paver block is the density; high dense paver blocks can resist abrasion better and are more durable.

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